Epizootic of White Halo Fungus, *Verticillium lecanii* (Zimmerman), and Effectiveness of Insecticides on *Coccus viridis* (Green) (Homoptera: Coccidae) on Coffee at Kona, Hawaii.[1]

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ABSTRACT. Efficacy of Volck oil, Superior 70 oil, Mavrik Aquaflow (fluvalinate), and Safer's insecticidal soap against *Coccus viridis* (Green) was studied on coffee at Kona, Hawaii. No scales were found on Mavrik treated trees 20 days after treatment. Scale populations decreased on Volck oil, Superior oil, and Safer soap treated trees to levels significantly below controls at 28 days after treatment. Scale populations recovered to control levels by 106 days after treatment on all trees treated with oil or soap. *C. viridis* populations never recovered from the Mavrik treatment. *C. viridis* caused significant stunting of coffee trees when not controlled. Mavrik treated trees were significantly taller than all other trees.

An epizootic caused by the fungus *Verticillium lecanii* (Zimmerman) decimated *C. viridis* populations on all sampled trees. Fungus-infected scales first appeared ca. 2 weeks after the beginning of increased precipitation. The regression of percent fungus-infected scales with percentage of days with rain 2 weeks prior to the sample date was significant.

Green scale, *Coccus viridis* (Green), is a cosmotropical pest of coffee, cacao, citrus, *Plumeria*, *Gardenia*, guava, celery, and several other plants (Zimmerman 1948). *C. viridis* is usually of minor importance on healthy, mature coffee trees but is a serious pest of nursery stock and young trees (Haarer 1958). Green scale was first recorded in Hawaii in 1905 (Kotinsky 1905) and soon became an important pest of coffee at Kona (Illingworth 1929). Large populations of the scale often build up on coffee trees in Hawaii, followed by a blight of sooty mold which develops on the scales' excreted honeydew. The results are reduced yields or death of severely affected coffee trees.

C. viridis is often attended by various species of ants. It is generally believed that green scale can only build up large populations on coffee in Hawaii due to benefits derived from ant attendance; possibly due to ant predation on, or disturbance of, natural enemies. Ant attendance has been demonstrated to be beneficial to various Homoptera in a number of systems (Way 1963), and to *C. viridis* specifically (Beardsley 1952, Bess 1958). Research on the development of management techniques for green scale on coffee in Hawaii has therefore concentrated on the management of ant, as well as scale, populations.

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Verticillium lecanii (Zimmerman), an entomopathogen of *C. viridis*, occurs throughout the tropics of the world. It can cause spectacular epizootics of aphids and scales in tropical and subtropical areas (Hall 1981). Epizootics of *V. lecanii* on *C. viridis* have been investigated on guava in Hawaii (Beardsley 1952) and on coffee in India Easwaramoorthy and Jayaraj 1976, 1978), Java, Colombia, Puerto Rico, Sumatra, and Cuba (Kohler 1980).

This paper reports results of efficacy trials with four insecticides against *C. viridis* and the ant *Anoplolepis longipes* Jerdon. The occurrence and effects of a natural epizootic caused by the pathogenic fungus *Verticillium lecanii* on green scale in coffee at Kona, Hawaii also are described.

MATERIALS AND METHODS

Population fluctuations of green scale, *Coccus viridis* (Green), and its natural enemies were monitored from February 1988 through February 1989 on coffee trees (*Coffea arabica* L.) at Kona, Hawaii. Trees were all young seedlings which ranged from 40 to 50 cm in height. All trees had scale infestations at the beginning of the experiment. The experiment was set up in the middle of the field in a randomized block design with 6 trees per treatment. Volck oil, Superior 70 oil, Mavrik Aquaflow (fluvalinate), and Safer insecticidal soap were sprayed on the foliage until dripping at the rates of 2.5 oz/gal H_2O, 2.5 oz/gal H_2O, 2 oz/100 gal H_2O, and 2.5 oz/gal H_2O, respectively. An additional 6 trees were left unsprayed as a control. The number of healthy, parasitized, and fungus-infected scales were determined by visual inspection of four leaves from each tree before treatment, at weekly intervals for 20 weeks after treatment, and at biweekly intervals after that. The four leaves were randomly selected from among the young terminal leaves. The presence or absence and identity of ants on the trees were also noted. Maximum and minimum temperatures and precipitation were recorded daily at the University of Hawaii Kona Experiment Station, ca. 2.5 km from the field site.

Differences in scale populations and in tree heights among treatments were anlyzed using Analysis of Variance (Sokal and Rohlf 1981) and means were compared by Duncans' multiple range test (Duncan 1951). Relationships among scale, fungus, and parasite populations, temperature, and precipitation were analyzed using correlation and regression techniques (Sokal and Rohlf 1981).

RESULTS AND DISCUSSION

Effects of insecticides on scale populations and plant growth.

There were no significant differences among treatments in mean number of scales/leaf before treatment (Table 1). Scale densities declined to levels significantly below controls on trees treated with fluvalinate within 10 days after treatment. Fluvalinate eliminated scales from the trees within 28 days after treatment. Safer's insecticidal soap, Volck oil, and Superior 70 oil

TABLE 1. Mean number of *Coccus viridis* per coffee leaf from 6 replications of 4 leaves/tree at Kona, Hawaii.

Treatment	Days After Treatment							
	Pretreat.	10	20	28	42	57	97	106
Volck Oil	43.8a	35.9a	18.1b	24.9b	27.2b	28.6b	32.0b	30.7a
Superior Oil	50.5a	40.4a	27.4ab	18.6b	20.2b	21.1b	35.8b	34.4a
Fluvalinate	44.0a	7.6b	0.3c	0 c	0.1c	0.1c	0 c	1.3b
Safer's Soap	39.0a	30.2a	23.2ab	22.4b	23.3b	23.9b	32.5b	27.3a
Control	40.3a	37.8a	39.8a	45.5a	42.9a	41.4a	48.3a	26.2a

Means followed by the same letter in each column are not significantly different ($P<0.05$; DMRT)

reduced scale densities to levels significantly below controls within 28, 20, and 28 days after treatment, respectively. These treatments each reduced scale populations to ca. 50% of the controls. Scale densities gradually increased to control population levels after the initial post-treatment decline on Safer, Volck, and Superior treated trees (Table 1). No significant

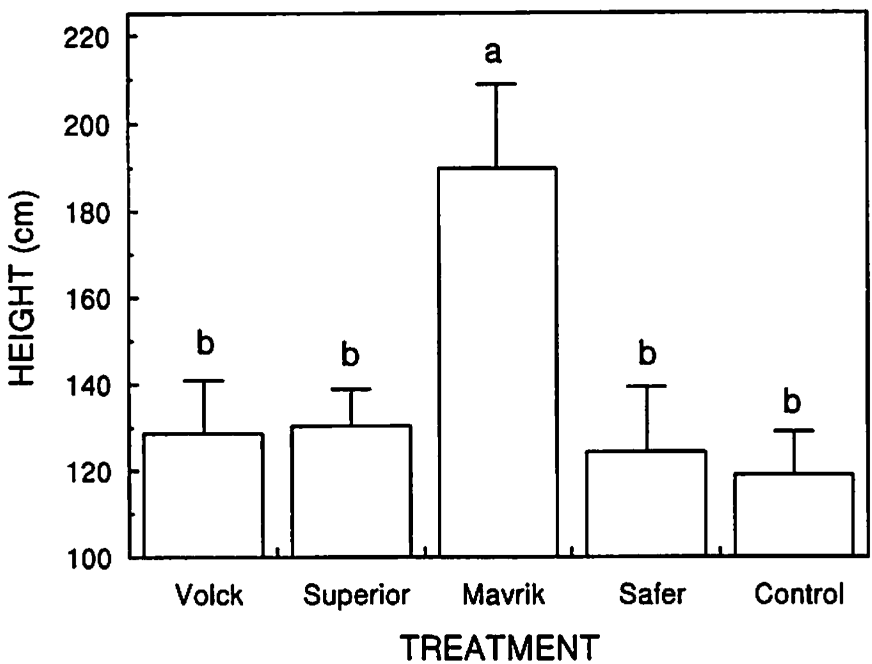

FIGURE 1. Mean height (cm) of coffee trees given various treatments, 16 months after treatment at Kona, Hawaii. Bars with the same letters are not significantly different ($P<0.05$; DMRT).

differences in the number of scales/leaf were detected among these treatments and controls 106 days after treatment. Scale densities remained near zero on fluvalinate treated trees.

The sprays had no apparent effect on ant activity. The ant, *Anoplolepis longipes* (Jerdon), was observed attending scales throughout the study.

Because of the virtual elimination of scales on fluvalinate treated trees, it was possible to test for the effects of *C. viridis* on tree growth. Comparisons of tree heights on June 2, 1989 (16 months after treatment) revealed that trees treated with fluvalinate (Mavrik) were significantly ($F = 28.19$; df $= 4, 25$; $P < 0.001$) taller than all other trees (Figure 1). There were no significant differences in height among trees not treated with fluvalinate. *C. viridis* was present on control trees and on trees treated with Safer's soap, Volck oil, or Superior oil up to 10-11 months after treatment. They were present at high densities for the first 6 months of this 10 month period and declined to 0 during the remaining months. It could not be determined how long high scale populations needed to remain on coffee to stunt trees because of the design of the experiment. However, these results demonstrated that *C. viridis* can stunt coffee tree growth when their populations build up and remain on young seedlings. The stunting was apparent up to 16 months after the initial green scale outbreak.

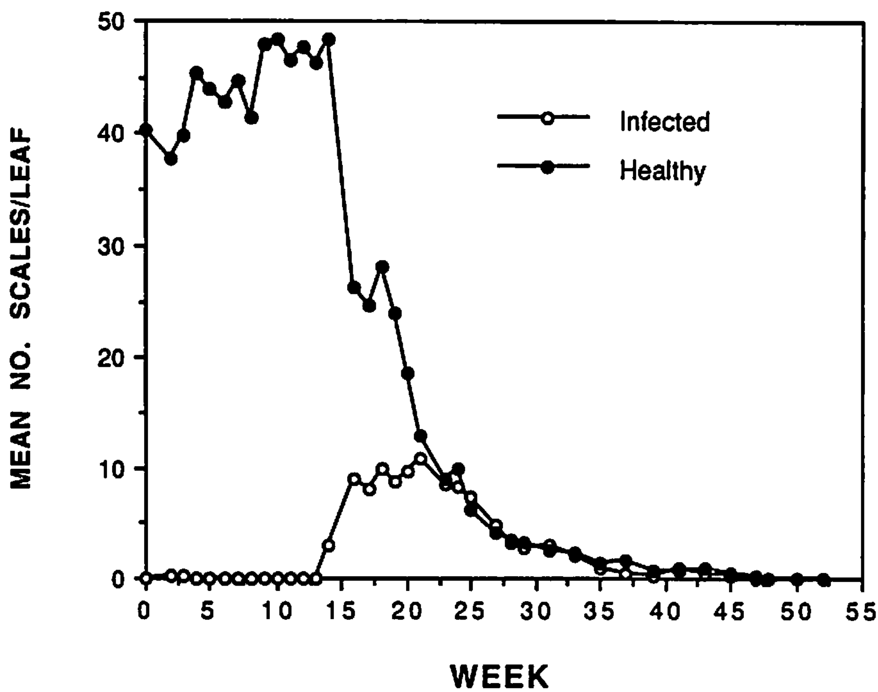

FIGURE 2. Mean number of healthy and fungus-infected *Coccus viridis*/coffee leaf, February 1988 to February 1989 at Kona, Hawaii.

TABLE 2. Correlation coefficients (r) of abiotic factors vs. green scale (no./leaf) infested with *Verticillium lecanii* at Kona, Hawaii.

Factor	r	Prob.
Average temperature	.75	<0.001
Maximum temperature	.72	<0.001
Minimum temperature	.66	0.002
Average weekly rainfall	.23	>0.05
Days/week with rain	.07	>0.05
Total rain 5 days prior	.17	>0.05

Effects of natural enemies on *C. viridis*.

C. viridis populations increased gradually on control trees for the first 13 weeks of the study (Figure 2). At 14 weeks, scale densities abruptly declined and continued to decline to 0 scales/leaf by week 48. The number of fungus-infected scales remained at zero until week 14, rapidly increased during weeks 14 and 15, and remained at high levels during weeks 16

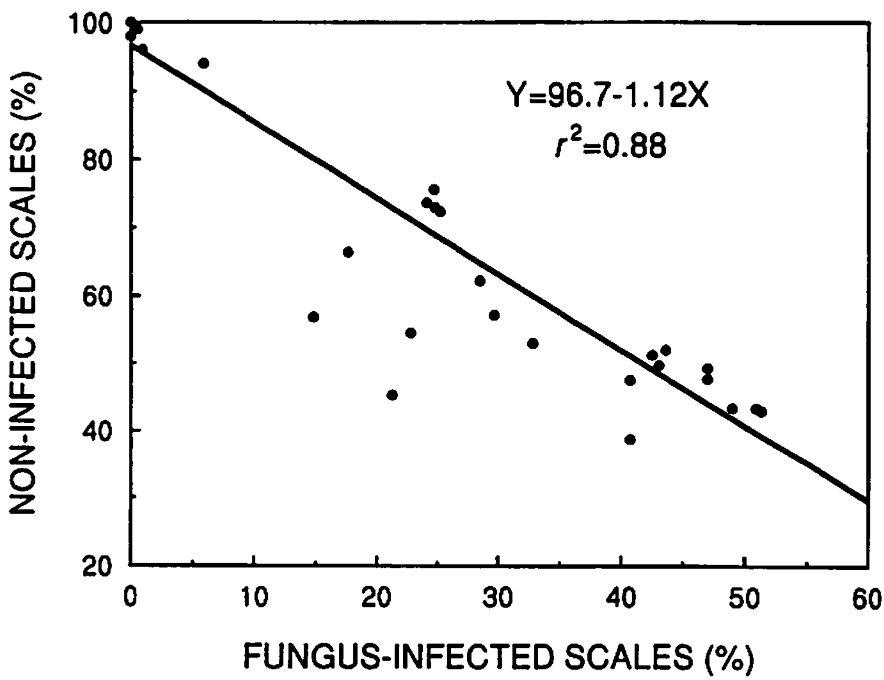

FIGURE 3. Regression of percentage of healthy scales vs. percentage of fungus-infected scales on coffee trees at Kona, Hawaii.

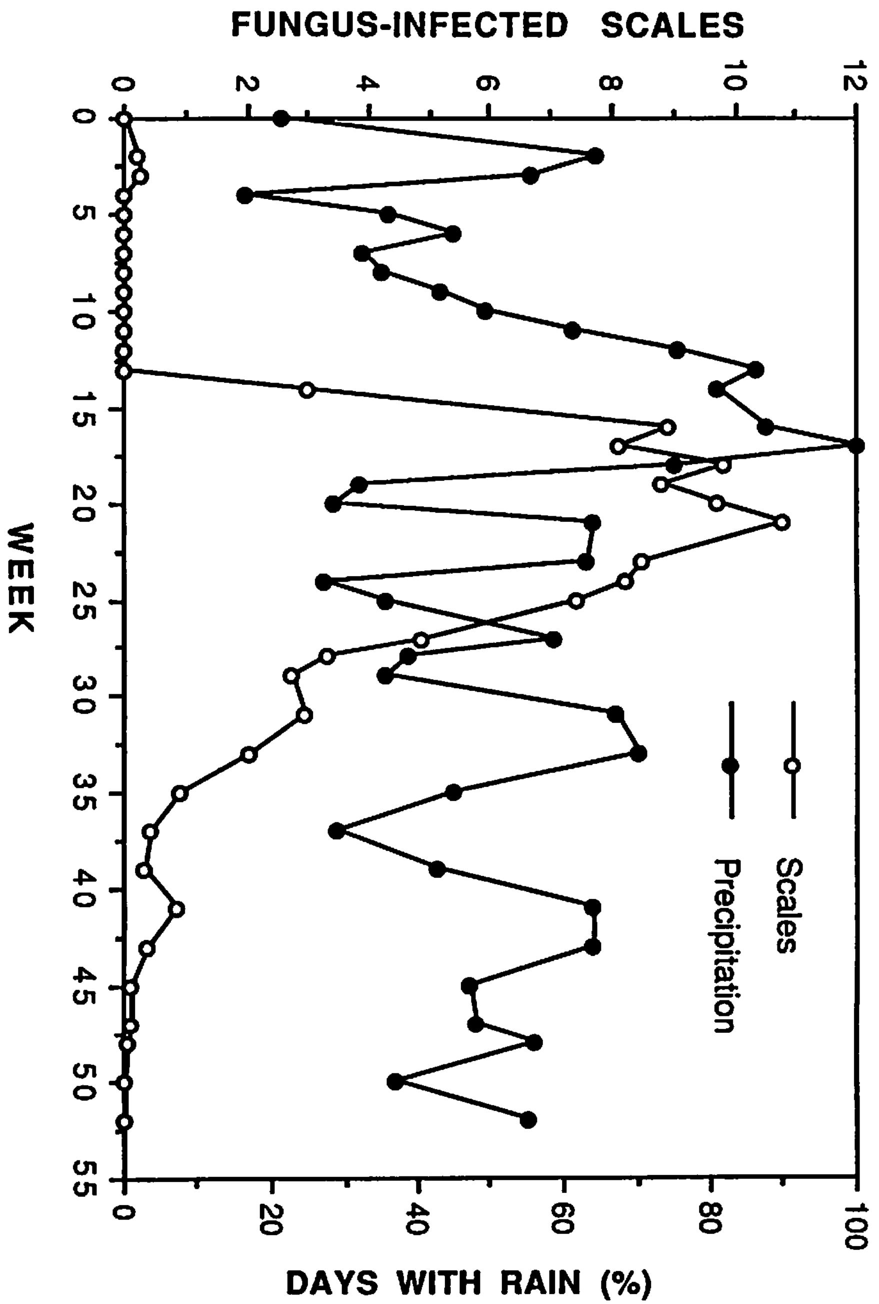

FIGURE 4. Relationship between mean number of fungus-infected scales per coffee leaf and percentage of days/week with rain at Kona, Hawaii from February 1988 to February 1989.

through 24 (Figure 2). Their numbers declined to zero during the following weeks. The increase in fungus-infected scales corresponded to the decrease in healthy scale populations. The regression of percent healthy scales with percent fungus-killed scales was significant ($F=246.2$; df$=1,35$; $P<0.001$). Changes in the number of fungus-killed scales explained 88% of the variation observed in healthy scale densities (Figure 3).

The regression of parasitized scales with healthy scales was also significant ($F=4.45$; df$=1,35$; $P<0.04$) but explained little of the variation in scale densities ($r^2=0.11$). Therefore, the decline in healthy *C. viridis* densities was not due to the corresponding increase in parasitized scales, but principally to an increase in the fungus disease.

Fungus-infected scale densities were significantly correlated with average, maximum, and minimum temperatures, but were not significantly correlated with rainfall (Table 2). However, an increase in fungus-infected scales occurred 2 weeks after the percentage of days with precipitation/week increased to greater than ca. 65-70% (Figure 4). The regression of the percentage of fungus-infected scales with the percentage of days with precipitation/week, 2 weeks prior to the sample date, was significant ($F=36.8$; df$=1,17$; $P<0.001$) when all samples after week 19 were excluded. These data were excluded because scale populations had declined, thus scales were unavailable for infection by the fungus. The equation of the regression line was $y=0.15\times-5.45$ with $r^2=0.75$. These results demonstrated that a period of wet weather was necessary for the infection and spread of *V. lecanii* throughout scale populations at the experimental site. The 2 week lag period between precipitation and onset of the epizootic can be explained by the developmental rate of the fungus. Beardsley (1952) showed that the white halo of hyphae, which protruded from underneath infected scales, appeared ca. 9 days after inoculation in laboratory studies. This corresponds well with the 2 week lag observed in this field study.

Relative humidities above 93% were prerequisites for infection and sporulation of the fungus in aphids (Milner and Lutton 1986) and whiteflies (Drummond et al. 1987); however, the highest infection rates occurred in *Myzus persicae* (Sulzer) when free water was present (Milner and Lutton 1986). Additionally, Kohler (1980) found that outbreaks of the fungus on green scale on coffee grown in Cuba occurred during the rainy season and control by this fungus was most effective on scales on shaded plants. Easwaramoorthy and Jayaraj (1976) also found humidity and rainfall to be positively correlated with infections by the fungus but felt that maximum and minimum temperatures were more important.

The significant correlation of fungus-infected scales with temperature in our study (Table 2) would at first appear to agree with Easwaramoorthy and Jayaraj's (1976) conclusion that temperature was a major factor in the infection and spread of fungus among scales. However, the temperatures observed during our study were always within the optimum (Hall 1981) necessary for germination and growth of the fungus. Therefore, fungus incidence increased as temperature increased but there may not have been a cause and effect relationship as there was with precipitation.

CONCLUSIONS

Fluvalinate (Mavrik) caused a dramatic decrease in green scale populations to levels near zero in this study. The efficacy data from this study were submitted to the EPA which has since granted a label for the use of this product in coffee.

The results with Safer's soap, Volck oil, and Superior oil demonstrate that these materials show promise for incorporation into a green scale management program. However, further investigations of application rates and timing are needed for better suppression of green scale populations.

Results from this study suggest that the use of sprays for green scale management may only be needed during the dry season in the Kona area. The naturally occurring entomopathogenic fungus, *V. lecanii*, can cause epizootics on *C. viridis* during the wet season. However, *V. lecanii* will most likely not be effective in the dryer coffee growing areas of the state such as Kauai.

Verticillium lecanii was produced commercially in the past but is no longer available in the United States. Fortunately, the fungus occurs naturally in coffee growing regions of Hawaii. It may be possible to induce outbreaks of the fungus on *C. viridis* by increasing the moisture level within fields. Overhead sprinkler irrigation or the periodic wetting of trees during periods of green scale outbreaks may initiate fungus epidemics. These augmentation techniques should be investigated.

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